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Ion Beam Machining of Optoelectronic Components

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We produce very smooth vertical sidewalls with high anisotropy in III-V semiconductors by ion beam etching. These qualities are used to fabricate mirrors and deflect light in InGaAs and GaAs waveguide structures. Either a maskless technique, using a focussed ion beam (FIB), or a lithographically deposited mask followed by broad-beam etching (CAIBE) are employed to produce such facets. Here, we describe the two examples of application of high-resolution ion beam etching techniques towards miniaturizing optoelectronic devices. We show the conversion of an edge-emitting laser structure into a surface-emitting structure, by cutting 45° reflection mirrors, and the fabrication of a monolithic InP-based wavelength demultiplexer by etching a diffraction grating.

Edge-emission severely restricts the packaging of semiconductor lasers and their uses in addressable arrays, chip-to-chip communications etc. Although vertical cavity devices allow us to produce low-threshold surface-emitting lasers, they require either optimized crystal growth, or dielectric mirror deposition. Therefore, it is desirable to deflect the light emission of an edge-emitting laser heterostructure into the vertical direction. This is generally doned by either fabricating a second order grating, by folding the cavity using total internal reflection mirrors, or by etching vertical laser facets and an aligned 45° deflection mirror.

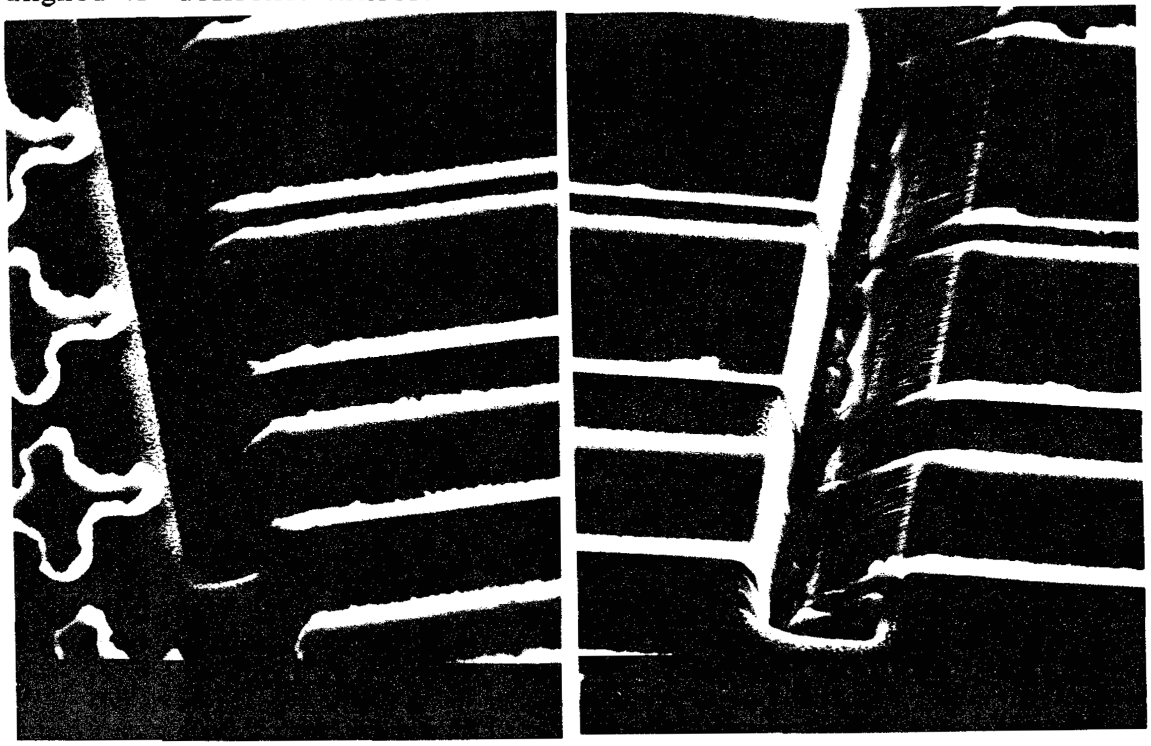

Figure 1 shows a SEM image of such a deflection mirror at the end of an edge-emtting laser structure. By altering the mirror geometry, (Figure 1a and 1b) we have investigated the dependence of our surface-emitting laser threshold currents on the light deflection method at the end of the facets. When a total internal reflection mirror is used to deflect the light from the waveguide to the sample surface, this results in additional losses as a result of three mechanisms: First, the light has to pass through an unguided region between the active region and the sample surface, resulting in high diffraction losses. Ordinarily, light emission is also only possible when an opening in the p-type metal contact is present, and the unpumped material underneath this opening re-absorbs some of the light from the active waveguide. Finally, inaccuracies in the angle, or roughness of the laser facet can result in less than perfect coupling of light back into the lasing cavity from the surface mirror.

A reflection-grating based multiplexer/demultiplexer was also defined by ion beam etching. This single grating demultiplexer was fabricated from OMCVD grown double heterostructure InP/InGaAs/InP planar waveguide material using a single photolithographic mask and a two-stage chemically assisted ion beam etching (CAIBE) process. Demultiplexing was achieved by a single vertically-etched focussing diffraction grating operating in reflection, and single-mode ridge waveguides providing the input and output ports. A Rowland circle geometry was used in an Eagle retro-diffractive configuration (Figure 2a). This "two-dimensional spectrometer" could demultiplex 78 channels with 1 nm resolution. Isolation from combined nearby channels (Figure 2b) was better than 19 dB, with more than 30 dB isolatio obtained form a single channel far removed in wavelength. Grating losses are estimated as 9 dB, a value which may be reduced by operating in a lower diffraction order (currently 18th order) and by further improving the quality of the diffraction grating wall.